N66 32951

CONTROLLABLE α/ϵ RATIO SURFACES FOR TEMPERATURE REGULATION OF SPACECRAFT

By William J. O'Sullivan, Jr.

ABSTRACT

The research and development program on Controllable α/ϵ Ratio Surfaces for Temperature Regulation of Spacecraft of the Space Vehicle Branch, Applied Materials and Physics Division, NASA, Langley Research Center is described in its entirety. There is given the technical background defining the problem, the possible solutions found from application of electromagnetic and quantum mechanics theory, the classification of the potential solutions by method of operation into thermotropic and nonthermotropic types, the experimental research program and its division into Phase I aimed at obtaining basic data on the phenomena and Phase II aimed at engineering development of the most promising methods, details of operation of the change in transparency method representing the most successful thermotropic method found to date, and details of the Electroluminescence method representing the most successful nonthermotropic method found to date.

CONTROLLABLE α/ϵ RATIO SURFACES FOR TEMPERATURE REGULATION OF SPACECRAFT

By William J. O'Sullivan, Jr.

1. Introduction.- The Langley Research Center's Space Vehicle Branch is engaged in a research program consisting of the devising, exploratory investigation, and development of what it calls Controllable α/ϵ Ratio Surfaces for Temperature Regulation of Spacecraft. The optical property α is the absorptivity of the spacecraft's surface to solar radiation, and ϵ is its emissivity to thermal radiation. This paper briefly describes the concepts of these controllable α/ϵ ratio surfaces and the progress to date in their development.

2. Technical background.- It is probably now a matter of common knowledge that in the hard vacuum of space a spacecraft can receive and lose heat only by the process of radiative heat exchange. A general proof has been developed (ref. 1) that the temperature of a spacecraft of any given configuration whose exterior surfaces have fixed ratios of α/ϵ, depends only on three things: (1) The location of the spacecraft relative to external sources of heat, that is, the sun and any nearby planetary body like the earth or moon. (2) The attitude of the spacecraft relative to these external heat sources. (3) The rate of heat release inside the spacecraft from chemical or nuclear energy sources. There is no possible orbit or spacecraft mission of any consequence in which all three of these factors can remain constant. Depending on the particular spacecraft mission and

orbit, designers have resorted to various fixes to hold the temperature of the spacecraft within permissible limits, but always at some penalty. Spinning has been used to expose all sides equally to the incident radiation, but this is incompatible with most missions. Mechanical shutters have been used to change the α/ϵ ratio of the exterior surfaces, but these are heavy and degrade reliability. Heat has been released internally and thermal insulation used, but this is heavy and consumes precious onboard power. Fixed orientation toward the sun has been used, but this requires a control system and continuous expenditure of mass to operate control jets. So many spacecraft designers have voiced their wish for a surface that would change its α/ϵ ratio spontaneously or on command as needed to hold the spacecraft's temperature constant that this imaginary surface has come to be known as a chameleon surface. The Langley Space Vehicle Branch's research program on controllable α/ϵ ratio surfaces is a deliberate attempt to devise and develop such surfaces that are practical and reliable.

3. Development of basic concepts.- The first step carried out in the Langley Space Vehicle Branch's program was to discover ways of getting changeable α/ϵ ratio surfaces. To find this out a search (ref. 2) was made deep into theory, especially electromagnetic theory and quantum mechanics, to try to understand what basically caused the α and ϵ of surfaces to be what they are, and whether there was any relationship between them. It was found that theory was very speculative and poorly developed in this area, but the phenomena seem to depend in large measure

upon the electron population within the material, with the result that anything that can change the electron population should change the α/ϵ ratio. With this clue as a guide, search was then made for materials and phenomena by which change in the electron population could be accomplished, and a surprising number were found (ref. 2). Change in electron population is to be understood in the broad sense of meaning not simply the number of electrons per unit volume, but also their degree of mobility or lack thereof, and their position within the molecular and crystal structure. Phenomena identified in this manner as being potentially capable of yielding controllable α/ϵ ratio surfaces were:

1. Electroluminescence
2. Semiconductors
3. Photoemissivity
4. Photoconductivity
5. Photovoltaic effect
6. Change in electrical resistance with temperature
7. Magneto-optical rotation
8. Polarization
9. Chemical indicators
10. Change in transparency

In addition, two mechanical-optical methods that will not here be discussed were found.

4. Classification by method of operation.- The ten aforementioned phenomena by means of which surfaces can be made whose α/ϵ ratio can be changed can be classified into two major groups with respect to how they would work. The previously mentioned study showing that the temperature of a spacecraft is a function of its α/ϵ ratio immediately indicates that change in α/ϵ ratio has to be controlled by the temperature of the spacecraft's surface. This immediately sorts the changeable α/ϵ ratio surfaces into two categories. (1) Those whose change in α/ϵ ratio is produced directly by a change in their temperature, for which reason they might be called thermotropic surfaces. (2) Those whose change in α/ϵ ratio is produced by some means other than temperature, and for distinction may be called nonthermotropic.

The thermotropic type surface, when subject to solar radiation and at a temperature below its control temperature, has a high α/ϵ ratio and therefore absorbs more heat than it radiates so that its temperature rises. When it reaches its control temperature, it changes to a low α/ϵ ratio and emits more heat than it absorbs, and therefore its temperature starts to decrease. But this causes it to change back to a high α/ϵ ratio, and thus its temperature is automatically controlled to the temperature at which it undergoes its change from high to low α/ϵ ratio. The thermotropic type surface, since it spontaneously changes, probably represents the acme of reliability.

The nonthermotropic type surfaces operate with a thermostate or other temperature sensor attached to them to measure their temperature. When they are below their control temperature they have a high α/ϵ ratio and absorb more heat from the incident solar radiation than they emit, with the result that their temperature rises. When they reach their control temperature as detected by the temperature sensor, the temperature sensor commands the activation unit to change the α/ϵ ratio of the surface to a low value. The surface then emits more heat than it absorbs and its temperature starts to decrease. But this causes the temperature sensor to command the activator unit to change the surface back to a high α/ϵ ratio, and thus its temperature is automatically controlled to the control temperature at which the temperature sensor is set. Thus, by simply changing the control temperature setting of the temperature sensor the nonthermotropic type controllable α/ϵ ratio surface can be made to automatically control its temperature to any desired value over a range of temperatures. But this advantage is achieved at some increase in complexity, and hence decrease in reliability, over the thermotropic type surface.

It is to be noted that in both the thermotropic and the nonthermotropic type surfaces herein discussed, the change in α/ϵ ratio is a distinct step change as contrasted to the gradual change of α/ϵ with temperature that has been noted in some materials and proposed for use on spacecraft by others.

Of the preceding list of ten phenomena giving such controllable α/ϵ ratio surfaces, phenomena 1 through 5 and 7 through 9 can operate as non-thermotropic surfaces; phenomena 9 as either a thermotropic or nonthermotropic surface; and phenomena 6 and 10 as thermotropic surfaces.

5. Experimental research and development program.- The experimental research and development program worked out jointly between NASA Headquarters and the Langley Space Vehicle Branch is divided into two sequential phases.

Phase I is aimed at providing experimental measurements of the magnitude of the change in α/ϵ ratio that can be produced by each of the aforementioned ten phenomena and the temperature range over which they can be made to occur. On this basis the phenomena are being sorted to determine which are the most promising and worthy of being pursued further in Phase II, as well as to provide the foundation data needed for Phase II. Phase I is being carried out partly in-house and partly out-of-house by a Research Grant to Georgetown University. The division of the research between these two places is based upon the capabilities of the technical personnel at each location. Since suitable experimental apparatus for satisfactorily performing this research was not in existence, such had to first be designed, constructed, and brought into operation before the measurements could be made. This has been done and successful measurements have already been made on a number of the phenomena. This Phase I is still in progress.

Phase II is aimed at carrying out engineering development on the most promising phenomena resulting from Phase I. By engineering development is meant the host of problems associated with converting a device from a laboratory model into a practical thing for use on spacecraft, and includes such things as fabrication methods, quality and reliability controls and standards, and the like. Already, several of the phenomena have just reached this stage.

6. The change in transparency method.- The first of the thermotropic type surfaces to emerge from Phase I as definitely worthy of proceeding into Phase II is based on the change of transparency phenomenon which is number 10 of the preceding list. Its Phase I investigation was carried out at the Langley Space Vehicle Branch.

As shown schematically in cross section in figure 1, it consists of a layer of changeable transparency material that forms the exterior surface of the spacecraft, behind which there is a mirror coating, which in turn is backed up by an opaque rear layer that forms the skin of the spacecraft. The changeable material layer consists of a transparent matrix material, such as a plastic, in which there exists a dispersed phase shown schematically as little spherules. When the temperature of the spacecraft's surface is below the control temperature of the coating, the dispersed material is opaque and the coating is in the absorbing condition, having a high α/ϵ ratio so that it absorbs more energy from the incident sunlight than it emits, and its temperature rises. When it reaches the control temperature,

the dispersed material undergoes a phase change and becomes transparent, so that the incident light passes through the changeable transparency material, is reflected by the mirror backing, passes again through the changeable transparency material, and then out through its front face, so that the coating in effect has a low α/ϵ ratio, and its temperature tends to decrease. But if its temperature decreases, the dispersed material changes back to its opaque state and the high α/ϵ ratio is restored. The coating thus automatically regulates itself to the control temperature which is the temperature at which the change of transparency occurs in the dispersed material.

An almost infinite number of materials can be used as the dispersed material giving a vast range of control temperatures. The change from absorbing to reflecting condition occurs over a very narrow range of temperature depending on the purity of the material used, being in some cases tried only a fraction of a degree.

7. The electroluminescence method.- The first of the nonthermotropic type surfaces to emerge from Phase I as definitely worthy of proceeding into Phase II is based on the electroluminescence phenomenon which is number 1 of the preceding list. Its Phase I investigation was carried out at Georgetown University.

As shown schematically in cross section in figure 2, it consists of a layer of electroluminescent material having a transparent electric conductor on its front face and an ordinary electric conductor on its back,

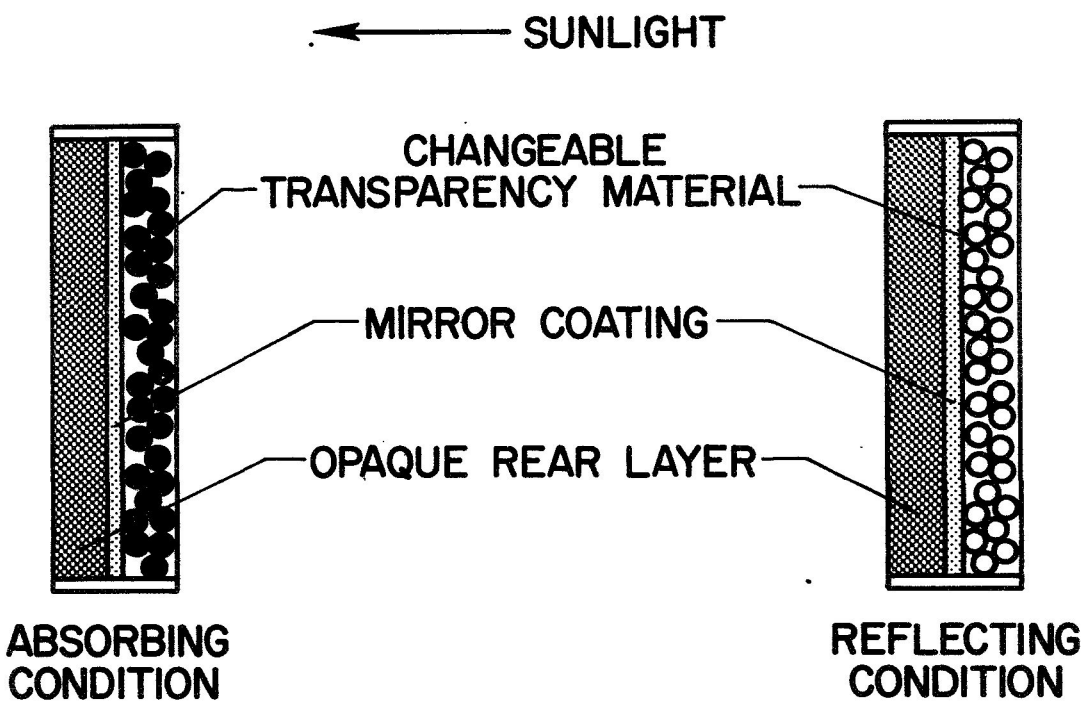
thus forming a capacitor in which the electroluminescent material is the dielectric. This three-layer sandwich is mounted on the exterior of the spacecraft's wall with the transparent electric conducting layer facing outward. Mounted on, or imbedded in, the inner side of the spacecraft's wall is the temperature sensor. When the spacecraft's wall is below the control temperature, the electroluminescent material is in its high α/ϵ ratio state so that it absorbs more heat from the incident solar radiation than it emits, and therefore the temperature of the spacecraft's wall rises. When it reaches the control temperature, as detected by the temperature sensor, the temperature sensor actuates an electric switch, sending a command signal to the activator unit which the applies across the electroluminescent material the electrical potential necessary to change it to its low α/ϵ ratio state. The electroluminescent material then absorbs less heat from the incident solar radiation than it emits so that the temperature of the spacecraft's wall starts to decrease. But any decrease is immediately detected by the temperature sensor which signals the activator unit to change the potential on the electroluminescent material so as to change it back to the high α/ϵ ratio state. Thus the temperature of the spacecraft's wall is automatically regulated to the value of the control temperature set into the temperature sensor. On some electroluminescent materials tried the electrical power required to hold the electroluminescent material in the changed α/ϵ ratio state is less than 0.2 watt per square foot of surface, and thus the power consumption is extremely modest.

This, together with the very thin electroluminescent layer required, of the order of a fiftieth of an inch, which makes the surface very lightweight, indicates that the electroluminescence method is practical.

REFERENCES

1. NASA Grant No. NsG-428 to Georgetown University, May 14, 1963, Appendix A, Derivation of the Dependency of a Spacecraft's Thermal Balance on the α/ϵ Ratio, by W. J. O'Sullivan, Jr., Sept. 7, 1962.
2. NASA-Langley Memo. for Assoc. Dir. (Atten. E. C. Draley), Nov. 22, 1961, by W. J. O'Sullivan. Proposal of a Potentially Revolutionary Means of Accomplishing the Thermal Balance of Spacecraft and Request for Decision on Means of Pursuing This Idea.

SCHEMATIC CROSS-SECTION OF CHANGEABLE TRANSPARENCY TYPE OF CONTROLLABLE α/ϵ RATIO SURFACE



SCHEMATIC CROSS-SECTION OF ELECTROLUMINESCENT TYPE OF CHANGEABLE α/ϵ RATIO SURFACE